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Thermal Agitation of Magnetization in CoCrPt Perpendicular Recording Media

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***Abstract*—Magnetic and structural properties of CoCrPt based perpendicular recording media required to achieve both high thermal stability and low-noise performance are discussed, based on experimental results obtained using a pulse magnetometer. Experimental and theoretical analysis reveal that for CoCrPt based media of 20 nm thickness having the thermal stability factor $K_uV/(kT) \approx 80$, the maximum achievable value of the ratio of remanence coercivity to anisotropy field of grains, H_r/H_k, is $\sim$0.35. Furthermore, if the strictest condition of demagnetizing factor, 4π, for perpendicular media is assumed, in order to realize a large squareness M_r/M_s of nearly 1.0, which is required to resist the thermal agitation effect, we find that the value of perpendicular magnetocrystalline anisotropy, K_u, has to be more than 3 times larger than $2\pi M_s^2$.**

***Index Terms*—Intergranular exchange coupling, low media noise, perpendicular recording media, pulse magnetometer, remanence coercivity, thermal agitation.**

I. Introduction

HIGH THERMAL stability and low media noise performance are critical issues for perpendicular recording media to achieve high recording density beyond 100 Gbits/inch^2. The coercivity is theoretically predicted to equal the magnetic anisotropy field, H_k, in the CoCr based perpendicular media. However, the remanent magnetization curves measured by a pulse magnetometer directly showed that grain size reduction, which is necessary to reduce media noise, leads to reduction of coercivity [1]. Moreover, thermal agitation significantly reduces the remanence magnetization, resulting in thermal instability of recorded bits at low recording density.

In the present study, thermal agitation of magnetization, and its effect on magnetic properties are quantitatively evaluated using a pulse magnetometer [1], [2] for various kinds of CoCr based perpendicular recording media. Magnetic and structural properties required to achieve both high thermal stability and low-noise performance are discussed.

II. Experimental Procedure

$Co_{70}Cr_{20}Pt_{10}$, $Co_{68}Cr_{20}Pt_{10}Ta_2$, and $Co_{66}Cr_{20}Pt_{10}B_4$ perpendicular recording media were fabricated on glass disks using a mass production type of d.c. magnetron sputtering system. $Ti_{90}Cr_{10}$ films of 15 nm thickness were used for the seed layers of these media. $Co_{77}Cr_{19}Ta_4$/Ti (5 nm) perpendicular media [1] were fabricated using an UHV d.c. magnetron sputtering system. Remanence curves were measured at two different sweep-rates of applied field. One was measured at $\sim$10 Oe/s using a conventional electromagnet based VSM. Another was measured at $\sim 10^8$ Oe/s using a pulse field magnetometer (maximum field $=$ 13 kOe). The value of perpendicular anisotropy (magnetocrystalline anisotropy), K_u, was measured using a torque magnetometer.

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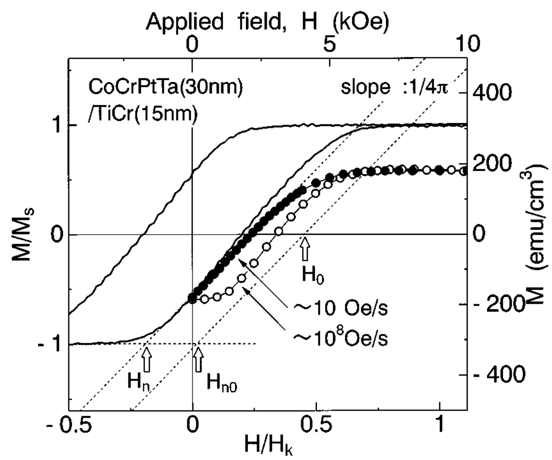

Fig. 1. Typical remanence curves of CoCr based perpendicular media (CoCrPtTa/TiCr medium).

III. Results and Discussion

A. Thermal Agitation and Remanence Curves

Fig. 1 shows remanent magnetization curves of CoCrPtTa (30 nm) medium, that are typical of those obtained from the CoCrPt based media. The value of remanence coercivity measured at a field sweep rate of $\sim 10^8$ Oe/s, H_r^P, is much larger than that measured at $\sim$10 Oe/s, H_r. The thermal effect is evaluated by fitting the values of H_r^P and H_r to the following equation [3], [4].

$$H_r(t') = H_0[1 - \{kT/(K_uV)\ln(f_0t'/0.693)\}^n] \qquad (1)$$

where,

f_0 is the frequency factor (assumed to be 5 $\times$ 10 ^{9}Hz),
k is the Boltzmann constant,
T is the absolute temperature and
V is the volume unit of magnetization reversal.

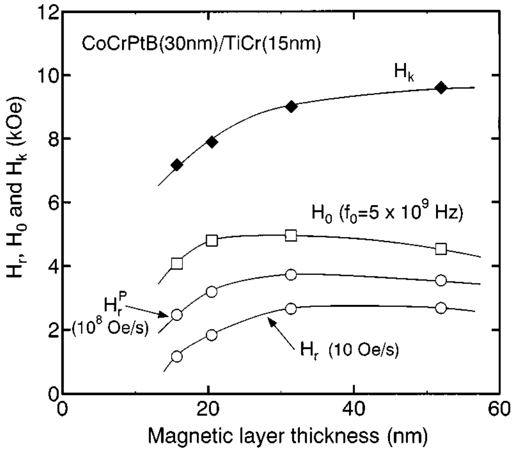

Fig. 2. Thickness dependence of H_r, H_r^P, H_0 and H_k for the CoCrPtB media.

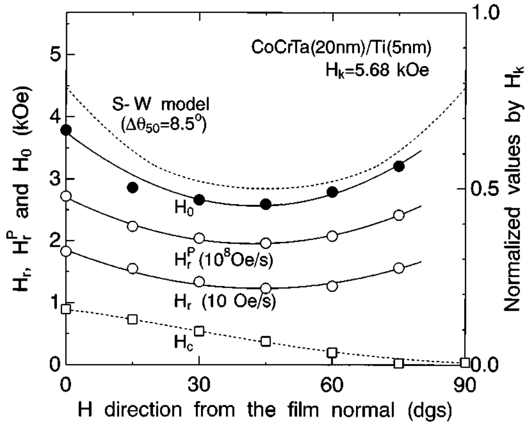

Fig. 3. Angular dependence of H_r, H_r^P and H_0 for CoCrTa medium with well-segregated Cr at grain boundaries. In the figure, the calculated H_r assuming S–W model is also shown for a comparison.

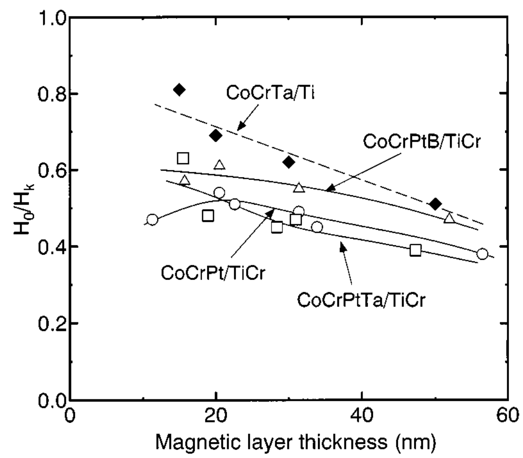

Fig. 4. Thickness dependence of the values of H_0/H_k for the CoCrTa and various kinds of CoCrPt based perpendicular media.

The n is a value between 0.5 and 1, dependent on the anisotropy axes orientation [4]–[6]. The H_0 corresponds to the value of "intrinsic" remanence coercivity obtained by subtracting the effect of thermal agitation of magnetization. The t' is the time needed for a constant field equal to H_r to reduce the magnetization from remanent saturation to zero. The values of H_0 and $K_uV/(kT)$ are obtained by fitting H_r, H_r^p, and corresponding t' values [3] to (1).

The remanent magnetization measured using the pulse magnetometer is almost constant at low applied fields, which indicates that the thermal relaxation of magnetization occurred immediately after the removal of a negative saturation field, due to the large demagnetizing field normal to the film plane. The estimated value of H_0 indicates that the "intrinsic" nucleation field H_{n0} is a positive value in this medium, with an approximation that the slope of the magnetization curve is proportional to $1/4\pi$, and the "intrinsic" squareness M_{r0}/M_s is very close to 1.0.

B. Remanence Coercivity and Squareness

Fig. 2 shows thickness dependencies of H_r, H_r^P, and H_0 for the CoCrPtB (30 nm)/TiCr medium. In the figure, the values of magnetocrystalline anisotropy field of the grains, $H_k(= 2K_u/M_s)$, are also shown. Here, M_s is the saturation magnetization, and the value of K_u was obtained by subtracting the $2\pi M_s^2$ value from the value measured by torque magnetometry. The values of H_r^P of these media are 1.5 $\sim$ 2 times larger than those of H_r. The "intrinsic" remanence coercivity H_0 is found to be 40 $\sim$ 60% of the H_k.

Fig. 3 shows the angular dependence of H_r, H_r^p and H_0 for the CoCrTa medium, which has fine, well-segregated grains of size of 11 nm with Cr at the grain boundaries [1]. The angular dependence of H_r, calculated assuming a magnetization switching in unison model (Stoner–Wohlfarth) and having a c-axis distribution equal to that of the medium ($\Delta\theta_{50} = 8.5°$ in the rocking curve), is shown for a comparison. The angular dependence of H_0 is in relatively good agreement with that obtained using the Stoner–Wolfarth model. This result implies that in CoCr media made up of well-segregated grains, reversal occurs by coherent rotation, and therefore validates the use of an analysis based on the Stoner–Wohlfarth model.

Fig. 4 shows the thickness dependence of H_0/H_k for the CoCrTa and CoCrPt based perpendicular recording media. The value of H_0/H_k gradually increases as the thickness decreases because of the reduction of intergranular coupling. It is likely that the distribution of easy axis directions and the residual intergranular coupling are dominant factors in the determination of H_0/H_k. The values of H_0/H_k of CoCrPtB are larger than those of CoCrPt and CoCrPtTa, which indicates that the addition of B to CoCrPt is effective in reducing intergranular exchange coupling. However, the H_0/H_k values for the CoCrTa media are much larger than those of the CoCrPt based media, indicating much smaller intergranular exchange coupling. In the Stoner–Wohlfarth model, a slight distribution of easy axis results in a significant reduction in H_0/H_k. A simple calculation assuming a Gaussian distribution of easy axis revealed that a $\Delta\theta_{50}$ value of 5 degrees, for instance, reduces the H_0/H_k value to 0.8. The achievable maximum value of H_0/H_k in CoCrPt based alloy films is likely to be $\sim$0.7 at 20 nm thickness even if the grains are segregated, as successfully as those of CoCrTa by controlling the film deposition process.

Fig. 5 shows the values of H_n and H_{n0} for the CoCrPt based media. The value of H_{n0} shows positive values at around 20 nm, indicating that the "intrinsic" squareness of the media is nearly

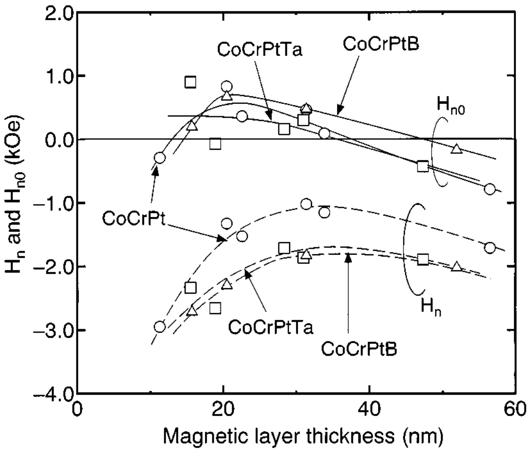

Fig. 5. Thickness dependence of the values of H_n and H_{n0} for the various kinds of CoCrPt based perpendicular media.

1.0 at around 20 nm. However, the values of H_n are negative and significantly smaller than those of H_{n0}, indicating large thermal reduction of remanence magnetization in a very short time. The values of $K_uV/(kT)$ were typically ∼180 for the CoCrPt (20 nm) medium and ∼100 for the CoCrPtTa (30 nm) and CoCrPtB (30 nm) media [7]. Although these $K_uV/(kT)$ values are large, the thermal reduction of coercivity reduces the remanent magnetization significantly, through the reduction of the nucleation field as seen in Fig. 1.

C. Required Properties

Sharrock's equation [3], [4] predicted that the H_r value is reduced to half that of H_0 due to the thermal agitation under an assumption of $K_uV/(kT) = \sim 80$. Moreover, the achievable maximum value of H_0/H_k in CoCrPt based alloy films is likely to be ∼0.7 at 20 nm thickness as mentioned above. Therefore, the maximum achievable value of H_r/H_k is likely to be 0.35, for media of 20 nm thickness, having the thermal stability of $K_uV/(kT) = \sim 80$. Moreover, to avoid the thermal reduction of remanent magnetization in the presence of the large demagnetizing field, a high squareness of ∼1.0 is the necessary condition since a large irreversible susceptibility at remanence gives rise to a large thermal reduction of magnetization [8]. A demagnetizing factor of 4π, which is the strictest condition for the perpendicular recording media, gives a critical condition that the nucleation field $H_n = (H_r - 4\pi M_s)/H_k$ in Fig. 1 should be positive to realize the squareness of ∼1.0. The above two conditions, $H_r/H_k = 0.35$ and $H_n > 0$, reveals that the value of K_u is required to be more than ∼3 times larger than $2\pi M_s^2$. If $K_uV/(kT) = \sim 80$ gives sufficient thermal stability, to meet the condition $K_u/2\pi M_s^2 = \sim 3$ requires values of $K_u = 2.2 \times 10^6$ erg/cm^3, $M_s = 340$ eμ/cm^3, $H_k = 12.9$ kOe and $H_r = 4.3$ kOe, for media of 20 nm thickness having a fine grain size of 10 nm. It should be noted here that these critical values are given under the strictest assumption of the demagnetizing factor, 4π. The decrease of the recording track width significantly reduces the demagnetizing factor [9], resulting in the required $K_u/2\pi M_s^2$ value to be smaller than 3. Moreover, local magnetizations close to the transition of recorded bits are thermally stable in the perpendicular recording media because of magnetostatic coupling, which means that effective value of K_uV is larger than the calculated value as a simple product of the K_u and grain volume. Therefore, the required K_u value is expected to be smaller than 2.2 × 10^6 erg/cm^3.

In the CoCrPt based media studied, the values of $K_u/(2\pi M_s^2)$ are 2 ∼ 2.4, independent of the addition of B and Ta, which are smaller than the required value of ∼3. For instance, the addition of B enhances the reduction of intergranular exchange coupling, but reduces both K_u and M_s. Moreover, the values of the H_0/H_k in the present media are smaller than 0.6, which is another factor leading to the reduction of squareness. The inducement of higher K_u and the further reduction of intergranular exchange coupling, by controlling the composition and deposition conditions, are vital to increase the value of M_r/M_s in the CoCrPt-(Ta,B) media.

IV. Conclusion

Magnetic and structural properties of CoCrPt based perpendicular recording media required to achieve both high thermal stability and low-noise performance have been discussed, based on experimental results obtained using a pulse magnetometer. Experimental and theoretical analysis revealed that the maximum achievable value of the ratio of remanence coercivity to anisotropy field of grains, H_r/H_k is found to be ∼0.35, for the CoCrPt based media of 20 nm thickness having the thermal stability of $K_uV/(kT) = \sim 80$. It is revealed that the value of perpendicular magnetocrystalline anisotropy, K_u, is required to be more than 3 times larger than $2\pi M_s^2$, in order to realize a large M_r/M_s of nearly 1.0 resisting the thermal agitation effect, assuming the strictest condition of demagnetizing factor of 4π for perpendicular media.

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